A COMPUTATIONAL APPROACH FOR DESIGNING TIGER CORRIDORS IN INDIA

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Abstract

Wildlife corridors are components of landscapes, which facilitate the movement of organisms and processes between intact habitat areas, and thus provide connectivity between the habitats within the landscapes. Corridors are thus regions within a given landscape that connect wildlife habitat patches in the landscape. The major concern of designing corridors as a conservation strategy is primarily to counter, and to the extent possible, mitigate the impacts of habitat fragmentation and loss on the biodiversity of the landscape, as well as support continuance of land use for essential local and global economic activities in the region of reference.

In this paper, we use game theory, graph theory, membership functions and chain code algorithm to model and design a set of wildlife corridors with tiger (*Panthera tigris tigris)* as the focal species. We identify the parameters which would affect the tiger population in a landscape complex and using the presence of these identified parameters construct a graph using the habitat patches supporting tiger presence in the landscape complex as vertices and the possible paths between them as edges. The passage of tigers through the possible paths is modelled as an Assurance game, with tigers as an individual player. The game is played iteratively as the tiger passes through each grid considered for the model. The iteration causes the tiger to choose the most suitable path signaling the emergence of adaptability.

As a formal description of the game, we model this interaction of tiger with the parameters as finite deterministic automata, whose transition function is informed by the Assurance game payoff.

Keywords: Landscape complex, Corridor, Assurance game, Graph theory, Chain code algorithm, Finite deterministic automata.

1. Introduction

Landscape linkage may be defined as the degree to which the landscape impedes or facilitates movement among resource patches (Taylor et al. 1993, 2006). We also define corridor as a habitat, usually linear, embedded in a dissimilar matrix within a landscape, that connects two or more bigger patches of habitat, thereby providing linkage between the habitats and that is proposed for conservation on the grounds that it will enhance or maintain the viability of specific wildlife populations in the habitat patches. Further, we define passage as travel via a corridor by individual animals from one habitat patch to another (Beier and Noss 1998).

Wildlife corridors, as implied from the definition above, are integral components of ecological landscapes. The objective of wildlife corridors is to facilitate the movement of processes and organisms between considered areas in the landscape. Corridors are thus regions within a given landscape that generally comprise native vegetation, and connect otherwise fragmented, disconnected, non-contiguous wildlife habitat patches – islands – in the landscape (Beier and Noss 1998; Chetkiewicz et al. 2006; Conard et al. 2010).

Corridors, being integral components of landscapes, are characterized by two distinct categories of components, namely, pattern and process components (Chetkiewicz et al. 2006). The structural corridor and the functional corridors present the categories of wildlife corridors. The structural categorization refers to the geographical existence of the landscape between the focal patches and the functional corridor is a resultant of both – species and landscape. Hence, a functional wildlife corridor refers to both, species - as well as landscape-specific concept. Corridors thus, may be considered as evolving phenomena, caused by the interaction between process and pattern attributes of the area. The essential function and utility of wildlife corridors is thus to connect at least two significant habitat areas of biological significance, and thus ensure gene flow between spatially separate populations of species, fragmented due to landscape modifications, by supporting the movements of both biotic and abiotic processes (Baum et al. 2004; Beier and Loe 1992; Beier and Noss 1998; Briers 2002; Chetkiewicz et al. 2006; Dutta et al. 2013; Henein and Merriam 1990; Johnsingh et al. 1990; Lindenmeyer et al. 2008; Pulliam 1988; Sharma et al. 2013).

Researchers have demonstrated that presence of species-specific wildlife corridors within a given landscape to be instrumental in increasing gene flow and population sizes of the species (Conard et al. 2010; Hanski and Gilpin 1991; Hanski 1998; Hanski and Ovaskainen 2000; Harris and Gallagher 1989).

The above discussions imply that any realistic modelling to design wildlife corridor has to be a species – specific task, with a proper choice of habitat for that focal species. In the present paper, we present a computational procedure for designing corridor for the Indian tiger (*Panthera tigris tigris*) in the Indian landscape. For a country biogeographically as vast and diverse as India, relative spatial location of tiger reserves with reference to one another becomes an important attribute to consider for making optimal decision for resource allocations, and thus either protecting existing tiger corridors, or even in some instances, creating proper wildlife corridors

in. A key objective in such a decision making therefore would be to select the critical tiger habitats (CTH) in a manner that their spatial configuration ensures a high degree of interconnectivity within often intensely human-dominated landscapes, over a long term land use scenario.

One means to achieve the above objective would be to design the interconnectivity among the existing (or even potential) habitats or CTH using a network model. In such a network, each tiger habitat would be treated as a vertex, and the tiger corridors between these vertices would be the edges.

The primary purpose of this paper is to provide a basic computational framework for perceiving a viable corridor network design in the focal landscape complex for tigers. In this work, all arguments are based on the structural definition of connectivity, where the viability and existence of a corridor is required to be determined entirely by the landscape structure.

We describe the problem of tiger corridor planning and designing within the landscape as a connection subgraph problem (Conard et al. 2010). We next incorporate the conflict of interest between the traversing tiger and the landscape features resultant of primarily anthropogenic modifications, through an Assurance game. Finally, informed about the possible costs, we provide an optimized path and thus use these optimized paths to design a Deterministic Finite Automata to obtain the grammar for designing corridors, which we claim, could serve as a rule base for corridor design.

Although the present work makes reference to a landscape map of the focal complex, it is essentially schematic and semi-emperical in nature. Accordingly, the discussions that follow do not refer to any real-world data as would have been obtained through a GIS routine. Since the work focuses on the presence or absence of corridors linking various tiger habitats in the complex, the distances involved, and the ease of movement for the tiger through these corridors, we are, however, of the opinion that the work could serve as a schema for an informed decision-making by conservationists and wildlife managers in designing real-world corridors.

Section 2 contains the essentials of the mathematical concepts that have been used in this paper. Sections 3 and 4 describe the modelling and the conclusion of the work, respectively.

2. Background for Modelling

In the present work, we shall describe a modelling of a feasible wildlife corridor for the tiger using few specific areas of computational mathematics. In this section, we shall provide the essentials of these areas, in order to make the work self-contained.

We apply game theory to model the effect of presence or absence of identified parameters in a grid leading to selection for movement by tigers. The choice of tigers for movement happens to be random but computationally what must be preferable according to the behavioral pattern of

tigers has been modelled here, which could act as an active strategy for designing the corridors. The results are in turn the consequence of essentially non-linear interactions among the parameters and tigers.

Assurance game, a generic name for the Stag Hunt game, best represents the present situation. In the modelling of the present interactions, we assume that set of parameters and tigers are players in the game, and thus accrues a quantum of pay-off depending on its own as well as its co-player's strategies. The game is iterated over time-steps for a countable number of steps to produce the complex dependencies of parameters affecting tigers.

Further, in Assurance game, a minimal cost must be contributed by all players if they are to receive any benefit from their own action. Thus, such a game would best capture the essence of coordinated, evolutionary and also since Assurance game properly describes such behaviors especially in the context of biological communities [31, 32, 33, 39].

To construct a rudimentary model of the interactions and consequent tiger movement, we assume that the Assurance game progresses by exchange of information between the players. Each tiger receives a finite number of input information from the contributing factor at each time step at a given state, and makes a transition to an unambiguously determined next state at the next time step. With this assumption, we design deterministic finite automata (DFA) to model the discrete movement dynamics of the focal species [18, 19, 23]. We propose that the functional characterization of corridors, exchange information using a context free grammar, which is obtained via the automata.

With the above agenda, we pose our research problem as: What are the DFA and the corresponding grammar that model the designing of wildlife corridors in Indian Landscape?

Let $G(\Theta,\Sigma,\Pi)$ be a normal form, strategic game where $\forall i \in I = \{1,\ldots,n\} \subset \aleph, n \geq 2$,

(i) $\Theta = \{\Theta_i\}$ is the set of interacting agents or players;

(ii) $\Sigma_i \neq \{\}$ is the set of strategies for the player Θ_i. $\Sigma = \Sigma_1 \times \ldots \times \Sigma_n$ is the space of strategies, with $\sigma = (\sigma_1,\ldots,\sigma_n) \in \Sigma$ being a strategy profile of the game G;

(iii) $\Pi_i : \Sigma \rightarrow \Re$ is the payoff function, which assigns to each strategy profile σ a real number $\Pi_i(\sigma)$, the payoff earned by the player Θ_i when σ is played in G. $\Pi = \Pi_1 \times \ldots \times \Pi_n$ is the space of payoff functions in the game.

Let the game G be repeated in periods of discrete time $t \in \aleph$. Assume that the players are 'hardwired' to play only pure strategies in G. Thus each strategy set Σ_i is a member of the standard basis for the strategy space Σ where the i^{th} coordinate is 1 and the rest are zeroes, and thus would correspond to a corner point of the simplex

$\Lambda = \left\{ \hat{p} = (p_1, p_2, ..., p_n)^T \in \Re : p_i \geq 0, i \in N, \sum_{i=1}^{n} p_i = 1 \right\}$, which is the simplex corresponding to Σ [19].

Let an n-player Assurance game be represented by $G(\Theta,\Sigma,\Pi)$, where $\Theta = \{\Theta_i\}$ is the set of players, with $i \in \Im=\{1,2,...,n\}$ a finite index set and $n \geq 2$. $\Sigma = \{\Sigma_i\}$ where Σ_i is the pure strategy set for each player Θ_i, with $\sigma = \{\sigma_1, \sigma_2, ..., \sigma_n\}$ where $\sigma_i \in \Sigma_i$ for $i \in \Im$ is a pure strategy profile of the game and $\Pi = \{\Pi_i\}$, the set of pay-off functions Π_i: $S \rightarrow \Re \ \forall \ i \in \Im$ where S is the set of strategy profiles, give the player's von Neumann-Morgenstern utility $\Pi_i(\sigma)$ for every profile.

Let the two pure strategies that the two players can opt for, be called cooperate (C) and defect (D), respectively, giving $\Sigma_i = \{C, D\}, i = 1,2$. The bounded simplex corresponding to G would be given by

$$\Lambda = \left\{ \hat{p} = (p_1, p_2)^T \in \Re : p_i \geq 0, i \in \{1,2\}, \sum_{i=1}^{2} p_i = 1 \right\} \subseteq \Re^2.$$

In the strategic form, G may be described by the following payoff matrix:

$$\begin{array}{ccc} & C & D \\ C & (R,R) & (S,T) \\ D & (T,S) & (P,P) \end{array}$$

With the row player being the first player Θ_1 and the column player being the second one Θ_2.
In the above game, both the players Θ_1 and Θ_2 have two pure strategies each to choose from: either play *C* or play *D*. If both play *C*, each obtains a reward *R* as the payoff for cooperating. If both play *D* instead, each obtains a punishment *P* for defecting, as the payoff. If one player plays *C* while the other plays *D*, then the one playing *D* obtains a payoff of temptation (to defect) *T* while the one playing *C* gets a payoff of sucker's, *S*. The game G is then defined by the constraint on the payoffs thus: $T > R > P > S$.
It is obvious from the foregoing discussion, that in a single shot, non-iterated game, the dominant strategy is *D*, and hence both the players, being rational, would choose to play *D* in order to maximize their individual payoffs. However, as the above game matrix shows, in an attempt to maximize individual payoffs, the players obtain equilibrium as (P,P), which, being Nash equilibrium, is a suboptimal solution of the game, the optimal solution being (R,R), that could have been obtained through mutual cooperation of the players. Selfish defection gives a higher payoff than cooperation but if both defect, condition is worse than if both cooperate (Hofbauer and Sigmund 1998; Webb 2007).

To obtain an understanding about the interactions between the parameters and tiger that leads to the designing of corridors in a landscape, we next study the Assurance game. The game is played

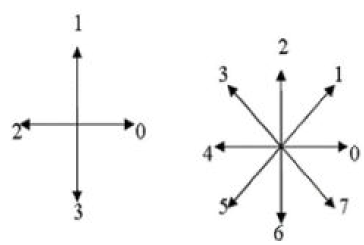
between Assurance game players. For analyzing this n-player Assurance game, we consider the pay-off matrix adopted from [4]:

	Propotion of cooperators in the group					
	100%	80%	60%	40%	20%	0%
C	20	14	8	1	-8	-15
D	6	6	6	6	6	6

The matrix shows pay-offs obtained by each player while playing against co-players who cooperate and interact. As could be observed from the payoff matrix, the scores from cooperative strategies for each player depend on the proportion of players who actually play C or play D in the entire population. It can be noticed that the pay-offs for the players playing C varies monotonically with the number of co-operators in the parameters. On the other hand, the pay-offs obtained by the player using the strategy of D remains constant irrespective of the number of players choosing to defect. This implies that the strategy selection of an Assurance game player depends on its expectations of the likely behavior of the similar players. If it expects that at least 80 % of its similar players in the parameters would play C, only then will it choose to play C. Else, it would change its strategy to D in order to obtain a higher pay-off.

A membership function (MF) is a curve that defines how each parameter in the input space is mapped to a membership value (or degree of membership) between 0 and 1. For the present modeling the input space is the total grid area which would considered for the landscape.

Chain code [12] is used to represent a boundary by a connected sequence of line. Typically this representation is based on 4 (or) 8 connectivity of the segments (as shown in figure1a, 1b). The direction of each segment is coded by using a numbering scheme.



(a) (b)

Fig 1. Neighbour directions of Chain Code

3. Modelling

For the purpose of the present work, we assume that the tiger habitat patches in India constitute the vertices and the collection of connections within this complex that connect any two of the habitats constitute the edges, comprising the focal landscape complex as a graph $\Gamma(V, E, \psi_\Gamma)$. The existence of an edge between any two vertices represents some ecological flux, such as animal movement, between the adjacent vertices.

To model the possible paths to serve as passages for tigers from one habitat patch to another habitat patch within any considered landscape complex, we first identify a set landscape factors or parameters, which may be natural or anthropogenic, and each of which may either constrain or support the passage of the tiger through the focal landscape matrix to various degrees, and hence become the major determinants in the structural connections becoming a corridor. For describing the present model, we consider five parameters *a, b, c, d* and *e*.

We assume that tigers in the landscape (Θ_1) and the set of above mentioned parameters of the landscape (Θ_2) constitute the two rational agents that play the Assurance game G iterated over a number of generations. The players may use a number of strategies in the game in order to optimize their payoff. These payoffs are the costs incurred by the tiger population (called tiger henceforth in the paper) in using the landscape matrix for movement between habitats.

Next we code the different tiger habitats included in the focal landscape complex, by the following table:

S.No	Tiger habitat	Code
1.	Habitat 1	1
2.	Habitat 2	2
3.	Habitat 3	3
4.	Habitat 4	4

Table 1 Coding for the tiger habitats in the complex

In order to explain the model we create a random landscape image as shown in figure 2.

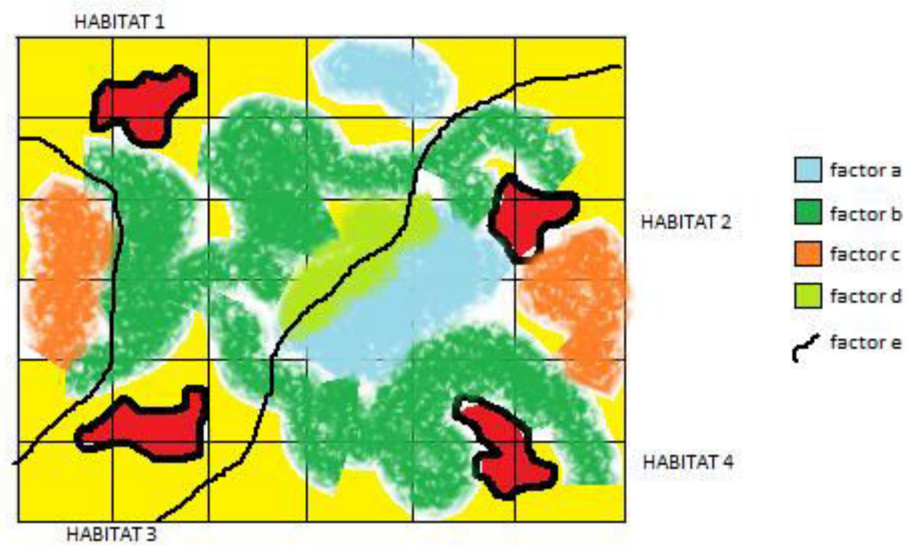


Fig 2. Sample landscape complex

Table 1 and the map in Fig. 2 lead to an adjacency matrix $A = [a_{ij}]$, $i = 1,2,...,n;\ j = 1,2,...,n$, where n = 4 for tiger habitat patches, which can be seen in Figure 4 and visualized through Figure 3.

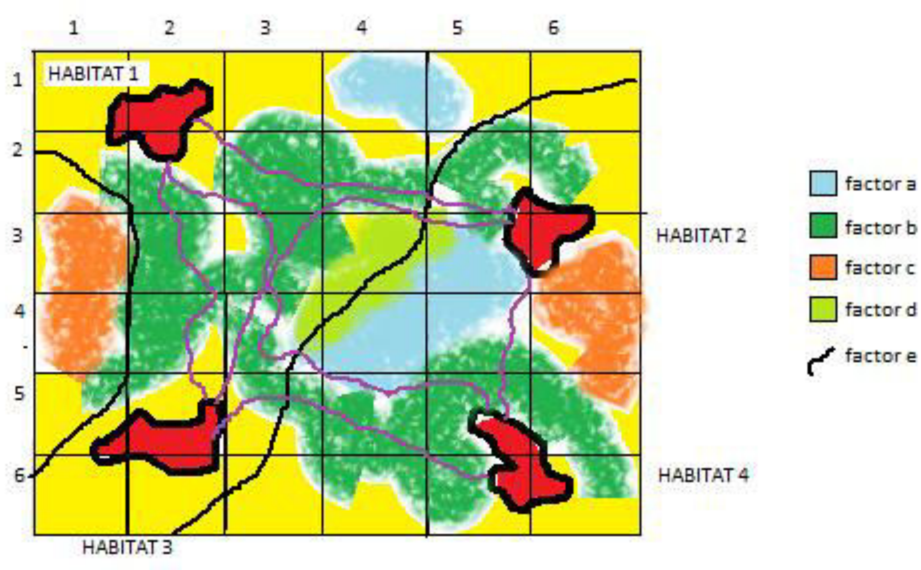


Fig 3. Sample landscape complex with connectivity.

	HABITAT 1	HABITAT 2	HABITAT 3	HABITAT 4
HABITAT 1	0	1	1	1
HABITAT 2	1	0	1	1
HABITAT 3	1	1	0	1
HABITAT 4	1	1	1	0

Fig. 4 Adjacency matrix A=[a_{ij}] for tiger habitats in the sample landscape complex

From the obtained adjacency matrix we can check that there exists connectivity between every patch but the basic question lies in finding the most feasible connection of the entire set of connections that would facilitate the passage of tigers with minimal loss. In order to find out such path, we next compute the costs incurred on tigers in using the connections between different habitat patches in the given landscape complex.

$$c : E \rightarrow \aleph$$
$$\ni e \mapsto c(e) = r \in \aleph, \forall e \in E, \aleph = \{0,1,\ldots\}.$$

In computing the cost matrix, we further create the Assurance game model using the contribution of each factor in the grid. Each factor of the landscape, due to its presence or absence contributes towards the cost matrix. For the present model, we consider 5 factors and categorize them as shown in Figure 5.

		Membership Contribution						
Factor	**Nature(Assumed)**	**1**	**0.8**	**0.6**	**0.4**	**0.2**	**0**	**EXAMPLE**
a	Cooperative	20	14	8	1	-8	-15	WATER BODY
b	Cooperative	20	14	8	1	-8	-15	FOREST COVER
c	Defecting	6	6	6	6	6	6	AGRICULTURE LAND
d	Cooperative	20	14	8	1	-8	-15	PREY BASE
e	Defecting	6	6	6	6	6	6	HIGHWAYS

Fig. 5. Factor categorization and score contribution

For the purpose of scoring, we make few assumptions for our model, which can be perfectly calculated once worked on with the Remote Sensing and GIS data. The assumptions made are:

1. The area of each grid in the landscape is constant = *A*.
2. The area occupied by a factor *f* in a grid G_{ij} denotes the membership of the factor in the considered grid and is given by:

   $\mu_{f/Gij} = A_{f/Gij}/A$
3. The score of each parameter in a grid is based on its categorization and then application of bilinear interpolation between the values considered. For e.g. if

   $\mu_{a/G14} = .7$, then

   $\pi_{a/G14} = \dfrac{14(.7-.6)+8(.8-.7)}{(.7-.6)+(.8-.7)} = 11.$

   Based on the above criteria of scoring, the various factors with respect to tiger using the membership of each factor in each grid and the strategy space of Assurance game the following cost matrix is obtained:

	HABITAT 1	**HABITAT 2**	**HABITAT 3**	**HABITAT 4**
HABITAT 1	∞	S12	S13	S14
HABITAT 2	S21	∞	S23	S24
HABITAT 3	S31	S32	∞	S34
HABITAT 4	S41	S42	S43	∞

Fig. 6 Cost matrixes of the tiger for using existing corridors between different habitat patches in the complex

For the present theoretical modelling we assume the following order of the scores, which can be correctly obtained using the presence, absence and abundance data of Remote Sensing and GIS:

S13 = S31 < S12 = S21 < S34 = S43 < S23 = S32 < S24 = S42 < S14 = S41

Using the above scores, we can rank the grids using the chain code algorithm which can be seen as:

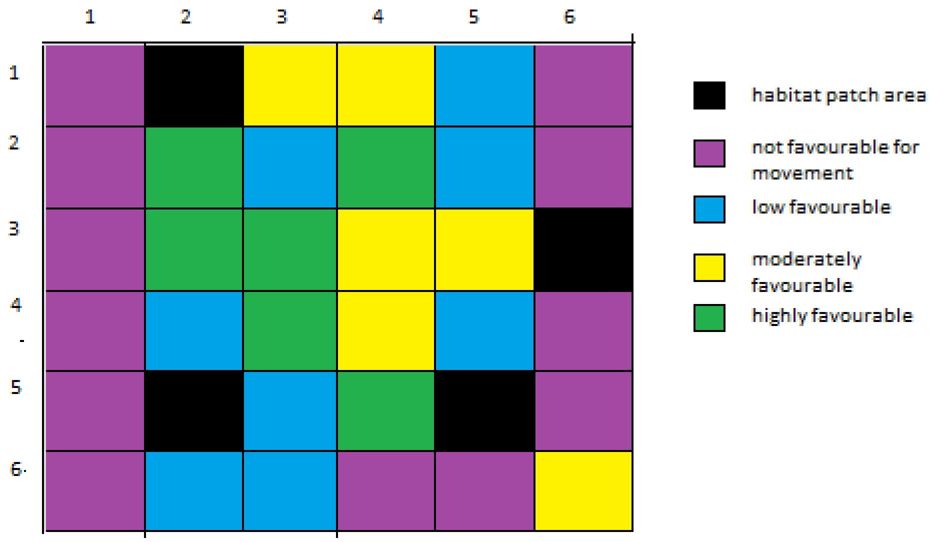


Fig. 7 Ranked grids using the cost matrix

Let the DFA that models the corridor designing and improving the landscape conditions for supporting movement of tigers be $\Delta(Q,\Sigma,q,\delta,h)$,where Q is the set of states, Σ is the alphabet, the set of input symbols or letters, $q \in Q$ is the initial state, δ is the transition function that prescribes the mapping of the automaton from one state to the next in time steps of $t \in N$, h is the set of final states, the theorems in a Turing machine[31, 32, 36].We list the objects comprising Δ in the following paragraphs:

Q comprises the following states, which represent the different states of grids that the tiger encounters while moving through it:

- Initial State(I)
- Not fovourable state(NFS)
- Fairly fovourable state(FFS)
- Moderately fovourable state(MFS)
- Fovourable state(FS)

The alphabet Σ = {a, b, c, d, e} comprises the letters (inputs for the automata), which are the parameters present in the grid to play G.

I is the initial state, representing the initial state of a grid which appears as the tigers move out from the territorial region. The transition function δ is described by the following matrix:

Letter ➡ State ⬇	a	b	c	d	e
I	MFS	FS	NFS	FFS	NFS
NFS	FFS	FS	NFS	FFS	NFS
FFS	MFS	FS	NFS	MFS	NFS
MFS	FS	FS	FFS	FS	NFS
FS	FS	FS	FFS	FS	NFS

Fig. 8 Transitions of Δ to various states

There exist two states which may be included in the state of final states which are:

- NFS: Not Fovourable for movement of tigers and thus cannot be supported or converted to corridor due to massive interferences from inhibitory sources.
- FS: Fovourable State for movement, as it supports the movement of tigers through them with highest priority.

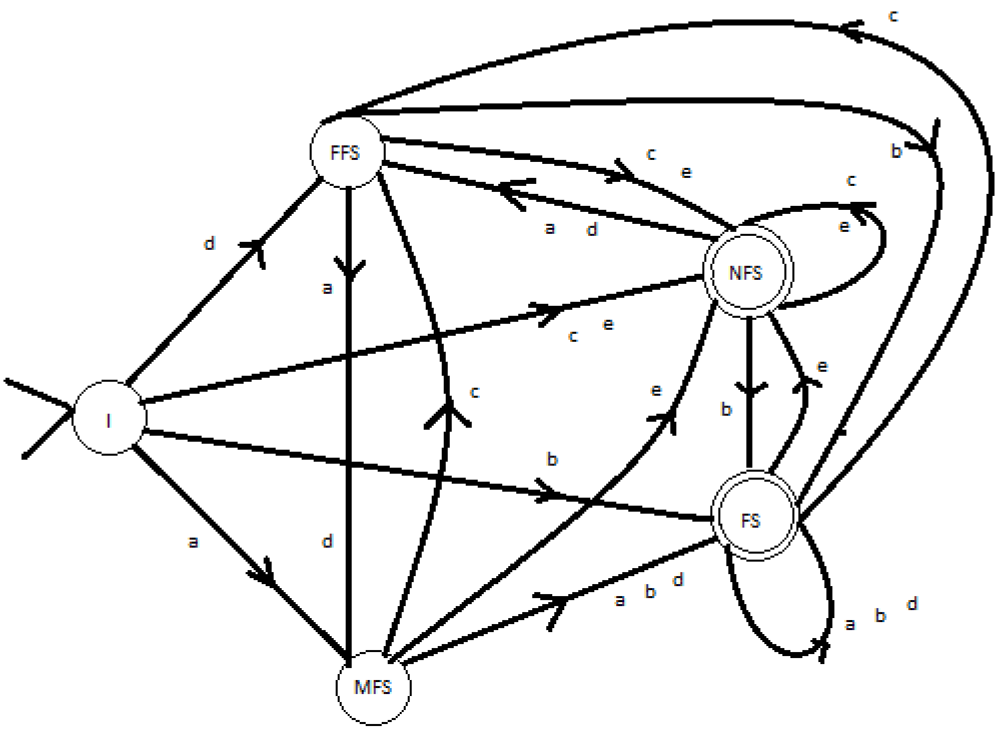


Fig. 9 DFA for grid state transitions to model wildlife corridors.

The above model of DFA would generate a standard context free grammar (CFG), which would, in essence, be determined by the transition function δ. Let the non-terminals in the DFA be denoted by Y. Y comprises the following states:

- I: Initial State (I)
- J: Not fovourable state (NFS)
- K: Fairly fovourable state (FFS)
- L: Moderately fovourable state (MFS)
- M: Fovourable state (FS)

Corresponding to such a set of non-terminal states, the context free grammar (CFG) couldbe written as

→ I→ cJ|aK|cL|Dm|eK

*J→ cJ|aK|cL|dM|eK

K→ cJ|aK|cL|dM|eK

L→ cJ|aK|cL|dM|eK

*M→ cJ|aK|cL|dM|eK

J, M is the final state of the automata, which, for the sake of identification, is prefixed by anasterisk sign.

4. Conclusion

The present work has been developed with objectives to (i) obtain a rule set to design a feasible tiger corridor network, connecting the habitat patches for the tiger in the landscape complex using a replicable computational procedure and (ii) identify the most important habitat patches, along with their underlying community structure so as to focus efforts towards conserving them.

In this paper, we have used Deterministic Finite Automaton to obtain a grammar that could serve as a model framework for a real-world tiger corridor designing in the Indian landscape.

A limitation in the modelling described in the paper is that the corridor designing is based entirely on the structural definition of connectivity, and thus does not take into account some critically vital landscape features such as the biotic factors of availability of prey base and water, in computing the cost matrix. The work is, by choice, kept rudimentary so as to provide a basic computational framework for perceiving a viable structural corridor network design in the focal landscape complex for tigers. We may justify this absence of path redundancy consideration due to two reasons: first, our priority in the paper was to focus on network efficiency over redundancy, and second, the work focuses on estimation of optimal strategies for connecting the CTHs, rather than inclusion of alternative paths [55]. We are aware that such a simplification is more often not in consonance with the real-world corridor scenario. We however hope that our

present effort would make available a computational template for tiger corridor designing, which could certainly be improved upon by incorporating field data from realistic considerations.

References

1. Axelrod, R., Hamilton, W. D., 1981. The evolution of cooperation. Science **211**: 1390 – 1396.
2. Axelrod, R., 1984. The Evolution of Cooperation, Basic Books Inc., New York.
3. Baum, K. A., Haynes, K. J., Dillemuth, F. P., Cronin, J. T., 2004. The matrix enhances the effectiveness of corridors and stepping stones. Ecology **85(10)**: 2671 – 2676.
4. Baland J.M., Platteau J.P., Halting Degradation of Natural Resources, Oxford University Press (1996).
5. Beier, P., Loe, S., 1992. A checklist for evaluating impacts to wildlife movement corridors. Wildlife Society Bulletin **20**: 434 – 440.
6. Beier, P., Noss, R. F., 1998. Do habitat corridors provide connectivity? Conservation Biology **12(6)**: 1241 – 1252.
7. Bonacich, 1972. Factoring and weighting approaches to status scores and clique identification. Journal of Mathematical Sociology **2(1)**: 113 - 120
8. Bondy, J., Murty, U. S. R., 2008. Graph Theory, Springer, New Delhi.
9. Bunn, A. G., Urban, D. L., Keitt, T. H., 2000. Landscape connectivity: a conservation application of graph theory. Jour. Environ. Manag. **59**: 265 – 278.
10. Cantwell, M. D., Forman, R. T. T., 1993. Landscape graphs; ecological modelling with graph-theory to detect configurations common to diverse landscapes. Landscape Ecol. **8**: 239 – 255.
11. Chetkiewicz, B. C-L., St. Clair, C. C., Boyce, M. S., 2006. Corridors for conservation: integrating pattern and process. Annu. Rev. Ecol. Evol. Syst. **37**: 317 – 42.
12. Dunne, J. A., Williams, R. J., Martinez, N. D., 2002. Network structure and biodiversity loss in food webs: robustness increases with connectance. Ecological Lett.**5**:558 – 567.
13. Dutta, T., Sharma, S., Maldonado, J. E., Wood, T. C., Panwar, H. S., Seidensticker, J., 2013. Gene flow and evolutionary history of leopards (*panthera pardus*) in central Indian highlands. Evolutionary Applications. doi: 10.1111/eva12078.
14. Digital Image Processing 2nd Edition by Gonzalez and Woods Pearson Publications
15. Fall, A., Fortin, M-J., Manseau, M., O'Brien, D., 2007. Spatial graphs: principles and applications for habitat connectivity. Ecosystems **10**: 448 – 461.
16. Gopal, R., Qureshi, Q., Bhardwaj, M., Singh, R. K. J., Jhala, Y. V., 2010. Evaluating the status of the endangered tiger *Panthera tigris* and its prey in Panna Tiger Reserve, Madhya Pradesh, India. Oryx **44**: 383 – 398.
17. Hanski, I., 1998. Metapopulation dynamics. Nature **396**: 41 – 49.
18. Hanski, I., Gilpin, M., 1991. Metapopulation dynamics – brief-history and conceptual domain. Biol. Journal of the Linnean Society **42**: 3 – 16.

19. Hanski, I., Ovaskainen, O., 2000. The metapopulation capacity of a fragmented landscape. Nature **404**: 755 – 758.
20. Harris, L. D., Gallagher, P. B., 1989. New initiatives for wildlife conservation: the need for movement corridors. In *Preserving Communities and Corridors* G. Mackintosh (ed.) Defenders of Wildlife, Washington D.C. pp.96.
21. Hofstadter D. R., Gdel, Escher, Bach: an Eternal Golden Braid, Penguin (2000).
22. Hopcroft J. E., Motwani R., Ullman J. D., Introduction to Automata Theory, Languages and Computation,
23. Addison Wesley (2006).Hofbauer, J., Sigmund, K., 1998. Evolutionary Games and Population Dynamics, Cambridge University Press, Cambridge.
24. Jhala, Y. V., Gopal, R., Qureshi, Q., (eds.) 2008. Status of Tigers, Co-predators and Prey in India. National Tiger Conservation Authority, Govt. of India, New Delhi, and Wildlife Institute of India, Dehradun. TR08/001 pp-151.
25. Jhala, Y .V., Qureshi, Q., Gopal, R., Sinha, P. R., (eds.) 2011. Status of Tigers, Co-predators and Prey in India, 2010. National Tiger Conservation Authority, Govt. of India, New Delhi, and Wildlife Institute of India, Dehradun. TR2011/003 pp-302.
26. Levett W. J. M., an Introduction to the Theory of Formal Languages and Automata, John Benjamins (2008).
27. Jordan F., Liu W. C., Davis A. J., 2006. Topological keystone species: measures of positional importance in food webs. Oikos **112**: 535 - 546.
28. Keitt, T. H., 2003. Network theory: an evolving approach to landscape conservation. In Ecological Modelling for Resource Management, Dale, V. H. (ed), Springer, New York.
29. Kruskal, J. B. Jr., 1956. On the shortest spanning subtree of a graph and the travelling salesman problem. Proc. Amer. Math. Soc.**7 (1)**: 48 – 50.
30. Nowak M. A., Sigmund K., A strategy of win-stay, lose-shift that outperforms tit-for-tat in the Prisoner’s
31. Nowak M. A., Sigmund K., Chaos and the evolution of cooperation, Proc. Natl. Acad. Sci. USA
32. Nowak M. A., Bonhoeffer S., May R. M., Spatial games and maintenance of cooperation, Proc. Natl. Acad.
33. Sci. USA 91(1994)4877 – 4881.
34. Minor, E. S., Urban, D. L., 2008. A graph-theory framework for evaluating landscape connectivity and conservation planning. Conservation Biol. **22(2)**: 297 – 307.
35. Opdam, P., Verboom, J., Powels, R., 2003. Landscape cohesion: an index for the conservation potential of landscapes for biodiversity. Landscape Ecology **18**: 113 – 126.
36. Opdam, P., Steingrover, E., van Rooij, S., 2006. Ecological networks: a spatial concept for multi-actor planning of sustainable landscapes. Landscapes and Urban Planning **75**: 322 – 332.

37. Ozgur A., Vu T., Erkan G., Radev D.R., (2008) Identifying gene-disease associations using centrality on a literature mined gene-interaction network. Bioinformatics **24(13)**: i277 – i285
38. Santos M., Szathmary E., The evolution of cooperation, Treballs de la SCB 60(2009)213 – 229. DOI:
39. 10.2436/20.1501.02.87.Pulliam, H. R., 1988. Sources, sinks and population regulation. American Naturalist **132**: 652 – 661.
40. Rayfield B, Fortin M-J, Fall A (2011) Connectivity for conservation: a framework to classify network measures. Ecology **92**(4): 847 – 858.
41. Taylor, P. D., Fahrig, L., Henein, K., Merriam, G., 1993. Connectivity is a vital element of landscape structure. Oikos **68**: 571 – 573.
42. Taylor, P. D., Fahrig, L., With, K. A., 2006. Landscape connectivity: a return to the basics. In: Connectivity conservation, Crooks, K.R. & Sanjayan, M. (eds.), pp.29 – 43, Cambridge University Press, Cambridge.
43. Urban, D. L., Keitt, T. H. 2001. Landscape connectivity: a graph-theoretic perspective. *Ecology* **82**: 1205 – 1218.
44. Urban D L, Minor E S, Treml E A, Schick R S (2009) Graph models of habitat mosaics. Ecology Lett. **12**: 260 – 273.
45. Webb, J. N., 2007. Game Theory: Decisions, Interactions and Evolution, Springer, New Delhi.
46. Wikramanayake E D, Dinerstein E Robinson , J G, Karanth U, Rabinowitz A, Olson D, Mathew T, Hedao P, Conner M, Hemley G, Bolze D (1998) An ecology based method for defining priorities for large mammal conservation: the tiger as case study. Conservation Biol. **12**(4): 865 – 878.
47. Wikramanayake E, McKnight M, Dinerstein E, Joshi A, Gurung B, Smith D (2004) Designing a conservation landscape for tiger in human-dominated environments. Conservation Biol. **18**(3): 839 – 844.
48. Yumnam B, Jhala Y D, Qureshi Q, Maldonado J E, Gopal R, Saini S, Srinivas Y, Fleischer R C (2014) Prioritizing tiger conservation through landscape genetics and habitat linkages. PLoS ONE **9**(11):e111207.